PATENT SPECIFICATION

DRAWINGS ATTACHED

897,417

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COMPLETE SPECIFICATION

Impingement Type Moisture Eliminator.

We, GENERAL DYNAMICS CORPORATION, a corporation of the State of Delaware, having a place of business at 445 Park Avenue, New York, New York State, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention is concerned with the removal of water droplets from a stream of moisture-laden air. Such removal has been effected by so-called moisture eliminators, some of which rely upon chemical methods and others of which rely upon mechanical methods. The former suffer because of the need to regenerate the chemical drying medium and also lack capacity, whilst the latter tend to introduce high pressure losses in the air flow system. Such pressure losses may, however, be reduced to a relatively low value in mechanical moisture eliminators of the so-called impingement type where the water droplets impinge against a surface which is intended to remove the droplets from the air stream. Even with impingement-type moisture eliminators, however, the pressure losses can be so great that they are not suitable for removing water droplets from a high velocity air stream, i.e. one having a speed greater than say 600 feet per minute. With some proposed impingement-type moisture eliminators, for example, the surfaces employed to remove the droplets are provided on members which would produce a significant degree of turbulence if employed with a high velocity stream, with consequential significant pressure losses. With other impingement-type moisture eliminators it has been found that pressure losses in some instances resulted from the formation on the impingement surfaces of water droplets which themselves cause turbulence. Such droplets are also torn from the impingement surfaces and thus reintroduced into the air stream, thereby reducing the efficiency of moisture removal well below its theoretical high figure.

According to the present invention, an impingement-type moisture eliminator is provided having a number of laterally spaced impingement rods each having in cross-section a rounded front and a tapered rear so as to present a streamlined shape, and each being covered with a water-absorbent material for forming from water droplets in impinging moisture-laden air an adherent film of water for draining by gravity from the rod. By the "front" of a rod is meant that part of the rod which the air is intended to reach first. With an eliminator according to the invention, the pressure losses may be reduced to a desirably low value and the eliminator therefore becomes suitable for use with high velocity air streams. The small losses of pressure are the result of making the rods streamlined and covering them with the water-absorbent material. When a sufficient number of water droplets have struck and been absorbed into this material, the material becomes saturated and covered by a film of water which tends to be driven towards the rear of the rods by the air stream passing over them, whilst the influence of gravity causes this film to flow downwardly along the rods. These two forces cause the water to drain along and off the rod coverings.

The water films on the rod coverings facilitate the retention of laminar flow boundary layer conditions along the streamlined rods. As a result, pressure losses are less than with prior impingement-type eliminators where water droplets are deposited on the impingement surfaces and cause there turbulent boundary layer conditions. Moreover, the water film resists tearing effects of the air stream and thus tends to prevent the reintroduction of the water into the air stream.

As previously indicated, an eliminator in

[*Price*

accordance with the invention finds particular utility when the air stream has a high velocity, for example greater than 600 feet per minute, and is thus useful in some cooling systems. Hitherto, some cooling systems which have operated at air velocities below about 600 feet per minute have used cooling or refrigerator coils as collecting surfaces for moisture condensed from air flowing thereover. However, it is often desirable to use air velocities in excess of 600 feet per minute with such cooling systems, for example 3,000 feet per minute, and at such high velocities, condensate tends to be torn from the cooling coils by the high velocity air stream and this causes excessive moisture in the ventilating or other system into which the cooled air is directed. This condition may be avoided by employing an impingement-moisture eliminator in accordance with the present invention with the cooling system.

When the eliminator is in use, it is preferred to dispose it so that the rods are arranged vertically so that gravity acts most efficiently to drain the water film.

Preferably the rods are arranged in rows, one row behind the other, and the rods in each row are preferably staggered with respect to the rods of the adjacent row or rows. With such a construction, the rods of the front row may be made wider than the rods of the other rows, and may be made more numerous than the rods of each of the other rows. With such an arrangement, the largest water droplets are captured by rods in the front row, whilst the subsequent rows catch the smaller water droplets.

In one preferred embodiment of the invention, the water-absorbent material is an absorbent cloth material. An important characteristic of this material is its ability to absorb quickly drops projected against it by high speed air flow. Such absorbency or wettability results in rapid saturation of the cloth and in the formation of the water film, which adheres strongly to the material and resists shearing effects of the high velocity air flow.

An eliminator according to the invention will now be described, by way of example, with reference to the accompanying drawings in which:—

Figure 1 is a perspective view, partially broken away, of a high air velocity cooling system incorporating this eliminator;

Figure 2 is a cross section of one of the streamlined impingement rods of the eliminator;

Figures 3 and 4 illustrate diagrammatically the way in which the water drains away under two different conditions from the impingement rods;

Figure 5 is a graph showing the efficiency of moisture collection of one eliminator in accordance with the invention and various air flow velocities compared to that of another moisture eliminator not in accordance with the invention: and

Figure 6 is a graph depicting for the purpose of comparison the pressure differential across a moisture eliminator according to the invention and across another impingement type eliminator (not in accordance with the invention) at various air flow velocities.

Referring to Figure 1, a cooling or refrigeration unit indicated generally by reference numeral 10 incorporates cooling coils and baffles 11 in suitable supporting structure. The unit 10 is designed to introduce relatively low pressure losses in a high velocity air flow system.

At the outlet side of the refrigeration unit 10 is located an impingement type moisture eliminator 12 in accordance with the invention. A three-sided sheet metal housing 13 and a collecting chamber 14 confine and direct the high velocity air flowing from the cooling unit 10 into impingement with a number of vertical, laterally spaced streamlined impingement rods 15 with water-absorbent coverings 16, and arranged in three rows, one behind the other, with their upper ends fastened to the housing 13. The rods in the first or front row, the second row and the third row are staggered to locate, in this instance, the second row rods intermediate the first row rods and the third row rods intermediate the second row rods.

The lower ends of the impingement rods 15 extend through the chamber 14 into attachment with supports 17 fastened across a collecting floor 18. A tube 19 is connected to an opening in the bottom of the chamber 14 to drain the chamber 14.

Rod sleeves 20 have their lower edges joined to the rods 15 and flare outwardly into an attachment with the edges of openings 21 in the roof of the chamber 14. Preferably the sleeve 20 is formed of an absorbent material, such as cotton wick cloth, which readily saturates and permits the passage of water therethrough while isolating the chamber 14 from the high velocity air stream flowing through the eliminator 12.

The cross section of the rods 15 consists of a rounded front and a tapered rear, the front being in the form of a part-circle joined tangentially to a pair of flat surfaces extending rearwardly to intersect at the trailing edge, as shown in detail in Figure 2. Such a configuration provides a relatively large target area for the moisture particles entrained in the high velocity air while introducing minimal pressure losses into the system.

As already implied, it is as a general rule the case that for greatest moisture collection efficiency the width of the front or leading edge of the streamlined rods is increased as

the size of the moisture droplets in the air stream become larger, and such increased width results in greater pressure losses. For example, if relatively large water droplets must be captured the rod width results in greater pressure losses. For example, if relatively large water droplets must be captured the rod width is increased until optimum collection efficiency is achieved or the pressure losses introduced by the unit become objectionable. On the other hand, if only small water droplets are to be encountered, the rod width is reduced to capture small droplets with the best possible efficiency and the number of rods increased by decreasing the spacing therebetween until the resulting pressure losses reach an objectionable value. Of course, any configuration selected should maintain air flow thereover with a minimum of turbulence to restrict pressure losses.

If a mixture of large and small water droplets must be removed from a high velocity air flow, the first or front row of rods 15 may be of relatively large cross section to capture the larger droplets, and succeeding rows may include greater numbers of smaller cross section rods to collect the smaller water droplets efficiently. Thus, any desired number of rows of differently sized and spaced rods may be used in accordance with the size of the droplets that must be removed from a high velocity air stream.

The coverings 16 of the streamlined rods 15 are formed of a material quickly absorbing water droplets striking the rods. It should be noted that certain materials ordinarily considered to be water absorbent do not meet the requirements of the invention in that they fail to absorb discrete water droplets impinging thereon by bombardment. In other words, the coverings 16 of the rods must saturate readily after being bombarded by the discrete water droplets and provide thereon a strongly adherent water film. One surface meeting those requirements consist of a fabric covering of a cotton muslin of the weave type having a weight of five ounces per square yard. The cloth may be secured to the rods 15 in any desired manner such as by gluing, stapling or through the use of two-surfaced pressure sensitive tape.

Diaper material also may be used to form the rod absorbent coverings 16. Still another useful cloth is an untreated herringbone cotton often used as wick material, for example, in wet bulb thermometers. A water absorbent flocked covering that will become saturated when bombarded by water droplets and provide a water film may also be utilized.

To clarify the invention it should be understood that the absorbent rod covering 16 becomes saturated when bombarded by moisture particles or droplets and forms such droplets into an adherent water film resisting the tendency of the high velocity air flowing thereover to reentrain it in the air stream. Since the water film is uninterrupted by droplets, a laminar flow boundary layer is formed on the streamlined rods 15. Moreover, due to its pliability the water film contributes to laminar flow conditions by conforming to the best possible surface configuration for such flow along the streamlined rods.

The mechanism of water drainage along one of the rods 15 at low and high velocities of air flow in the direction shown by the arrows is indicated by diagrammatic flow patterns in Figures 3 and 4, respectively. The water film on the rod 15 drains in those flow patterns as a result of gravity, the viscous or shear characteristics of water, the static and dynamic pressures of the flow urging the water film against the absorbent covering, adhesive forces holding the water to the absorbent covering, and the viscous or sheer characteristics of the air. Since the influence of gravity is relatively greater at low air velocities on the order of 500 feet per minute, for example, the water moves downwardly at a relatively sharp angle in Figure 3 to provide drainage at the rod bottom from a substantial area on the rod, shown lightly shaded in Figure 3. In contrast only a small area of the rod of Figure 4 subjected to air flowing on the order of 1500 feet per minute, for example, is drained in this manner.

Water film from the unshaded areas is swept along the rod and held on its trailing edge, as it drains under the influence of gravity, by the static pressure, and the cohesive and adhesive forces acting thereon, against the air flow shear forces. In other words, if the static pressure plus the cohesive and adhesive forces are great enough to overcome the shearing force on the water at the trailing edge, the film will drain downwardly. It should be noted that the streamlined shape of the rod 15 minimizes turbulence in the trailing edge region to assist in drainage of the water film.

An exemplary moisture eliminator in accordance with the present invention was constructed of three rows of fourteen vertical rods 12 inches long and formed with $\frac{3}{8}$ inch diameter circular leading edge from which extended tangent surfaces intersecting at a point $1\frac{15}{16}$ inches from the leading edge. The rods in each row were spaced $\frac{15}{16}$ inches apart measured from centre line to centre line, and the spacing between rows was two inches measured from leading edge to leading edge. The rows of rods were staggered, as shown in Figure 1, with the rods in each succeeding row positioned intermediate the rods of the row in front.

An untreated cotton muslin of the weave type weighing five ounces per square yard was used to cover each rod. The moisture eliminator was then positioned in an air stream

of variable velocity with suitable instrumentation to determine moisture collection efficiency from the air and the pressure differential thereacross.

The graph of Figure 5 shows moisture collection efficiency in percent plotted (along the vertical axis) against air flow velocity in feet per minute (along the horizontal axis). Curve *a* indicates a collection efficiency of about 99% at 600 feet per minutes declining to an efficiency of about 96% at 1500 feet per minute.

Figure 6 shows a plot of pressure differential in inches H_2O (vertical axis) against air velocity in feet per minute (horizontal axis). Curve *b* indicates that at a flow of 600 feet per minute there was a pressure differential of .105 inches H_2O across the unit and at 1500 feet velocity a pressure drop of about .345 inches H_2O.

To demonstrate clearly the advantageous characteristics of the present invention, an impingement type moisture eliminator not utilizing the principles of the present invention was tested under the same air flow conditions and the results also displayed in Figures 5 and 6 by curves *c* and *d*. The eliminator tested was identical to the inventive eliminator described except that the rods had smooth unabsorbent surfaces in contrast to the absorbent coverings on the rods 15.

Referring to Figure 5, in which curve *c* indicates a significantly lower moisture collection efficiency for the comparison eliminator, at 600 feet per minute about 95% efficiency was achieved which dropped to about 86% at 1500 feet per minute. Referring next to Figure 6, curve *d* indicates that the pressure losses introduced by the eliminator lacking an absorbent surface are substantially higher, being about .18 inches H_2O at an air flow velocity of 600 feet per minute and about .61 inches H_2O at an air velocity of 1500 feet per minute.

It will be noted that at an air flow velocity of 1500 feet per minute, the absorbent surface rods 15 with the coverings 16 show a 10% improvement in moisture collection efficiency over normally surfaced streamlined rods. Moreover, the pressure differential for the absorbent surface rods was between 40% and 45% less than that for the conventional rods.

The increased efficiency and decreased pressure losses attained with the inventive impingement type moisture eliminator apparently result from the formation of a water film on the streamlined impingement elements uninterrupted by water droplets which tend to create turbulence and to shear off into the air system. In contrast the water deposited on the smooth non-absorbent surfaces of prior impingement eliminators formed droplets which, when subjected to the high velocity air, were torn off and reentrained in the air flow. Such accumulated water droplets interrupted the streamlined shape of the rods and disturbed the laminar flow boundary layer causing turbulence and eddying which resulted in greater pressure losses.

Other tests conducted with impingement type moisture eliminators showed moisture collection efficiencies below and pressure losses above those achieved by the inventive eliminator. In one test in which a configuration included a separate series of deflector rods positioned in front of smooth non-absorbent streamlined rods, although the moisture collection efficiency characteristics approached those of the inventive eliminator the pressure losses were greatly increased to more than double those introduced by the inventive eliminator.

It will be evident that various absorbent coverings other than those particularly specified herein may be used to provide a thin water film uninterrupted by droplets in response to bombardment by high velocity moisture droplets in an air stream. In that regard, all absorbent materials for surfacing the impingement rods referred to herein and contemplated by the invention have in common the characteristics of absorbing and becoming saturated by bombarding water droplets to form a water film quickly over the entire surface of the material.

Moreover, the sizes of the moisture collecting impingement elements are chosen taking into account such factors as the air flow velocities, the amount of moisture and the size of the water droplets that must be removed. For example, one size of rod presenting a greater target area to the air stream to remove larger entrained droplets efficiently may be used in one row, even though it introduces somewhat greater pressure losses, while other sizes of rod presenting smaller target areas to collect smaller droplets more efficiently may be used in succeeding rows. Moreover, the size and spacing of individual rods in each row, the spacing and amount of staggering between rows, and the number of rows, must also be considered in connection with the requirements of any particular air flow system from which moisture is to be removed.

WHAT WE CLAIM IS:—

1. An impingement-type moisture eliminator having a number of laterally spaced impingement rods each having in cross-section a rounded front and a tapered rear so as to present a streamlined shape, and each being covered with a water-absorbent material for forming from water droplets in impinging moisture-laden air an adherent film of water for draining by gravity from the rod.

2. An eliminator according to claim 1, in which the rods are disposed vertically.

3. An eliminator according to claim 1 or

claim 2, in which the rods are arranged in rows, one row behind the other and in which the rods in each row are staggered with respect to the rods of the adjacent row or rows.

4. An eliminator according to claim 3, in which the rods of the front row are wider than the rods of the other rows and are more numerous than the rods of each of the other rows.

5. An eliminator according to any of the previous claims, in which the water-absorbent material is an absorbent cloth material.

6. An eliminator according to any of the previous claims, in which an opening is provided for the removal of drained water.

7. A method of removing water droplets from a stream of moisture-laden air in which the stream of air is made to impinge on a number of laterally spaced rods each having in cross-section a rounded front, which the air reaches first, and a tapered rear so that the rods present streamlined shapes, the rods being covered with water absorbent material which forms from the water droplets an adherent water film which drains from the rods by gravity.

8. A method according to claim 7, in which the air stream has a velocity in excess of 600 feet per minute.

9. An eliminator according to claim 1, substantially as described with reference to Figures 1 and 2 of the accompanying drawings.

10. A method according to claim 7, substantially as described.

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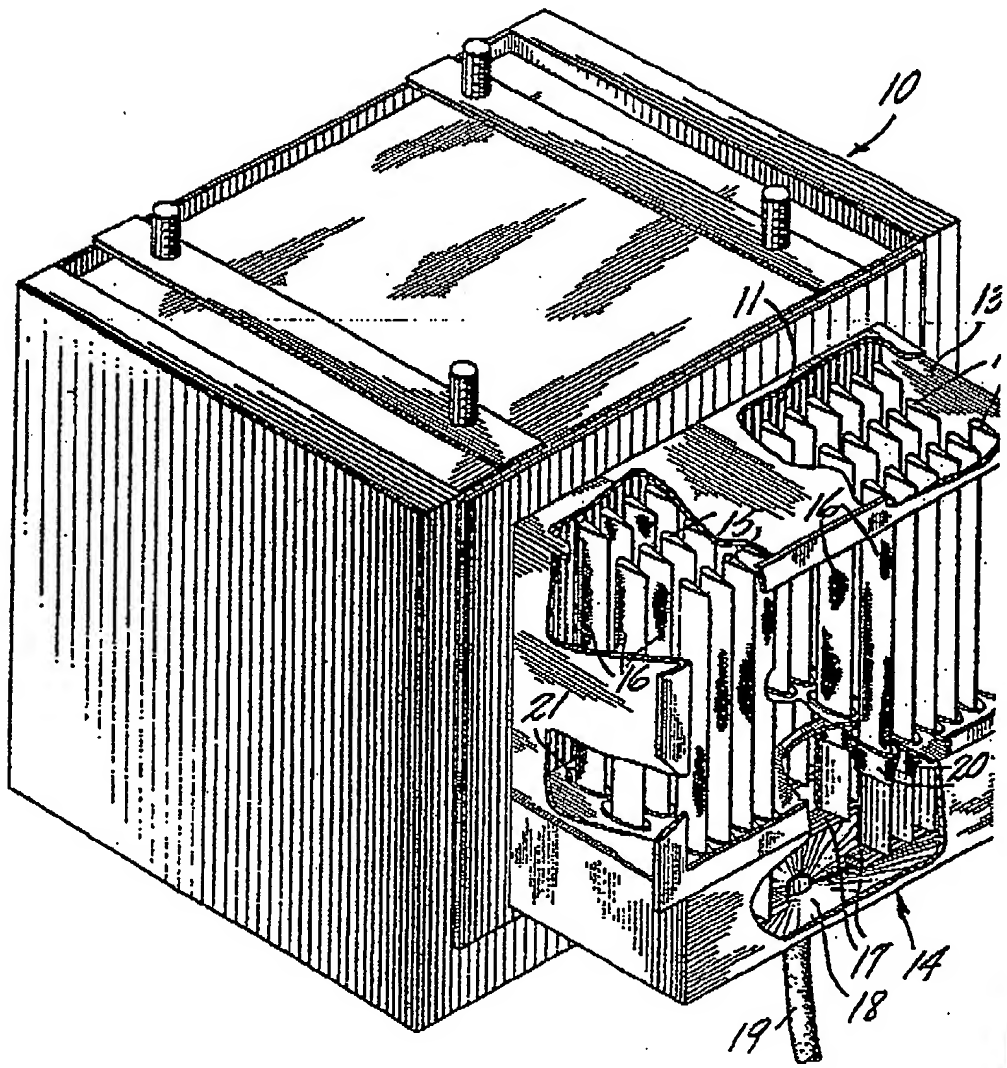

FIG. 1

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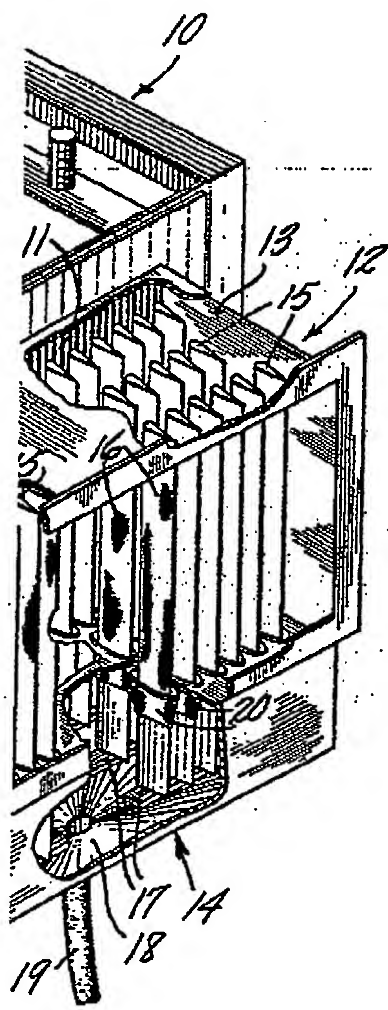

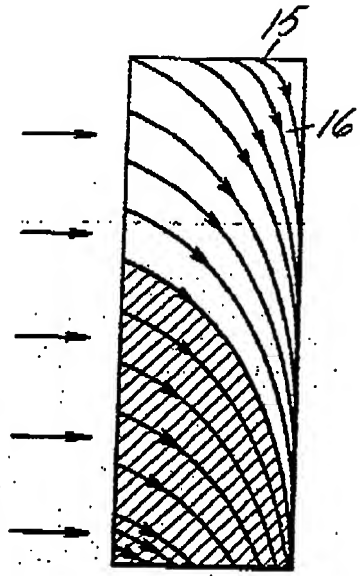

FIG. 3

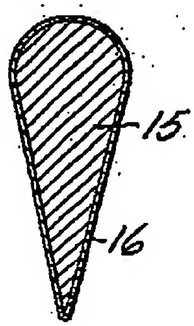

FIG. 2

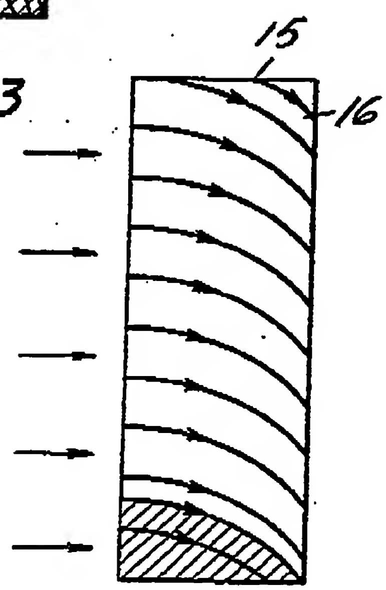

FIG. 4

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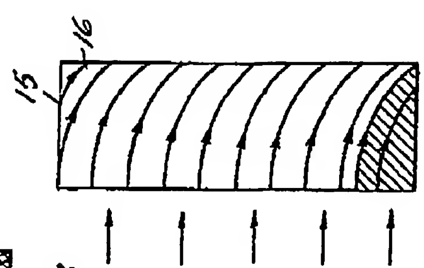

FIG. 4

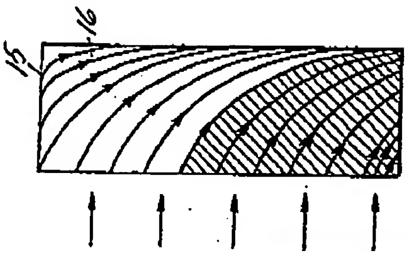

FIG. 3

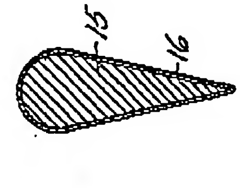

FIG. 2

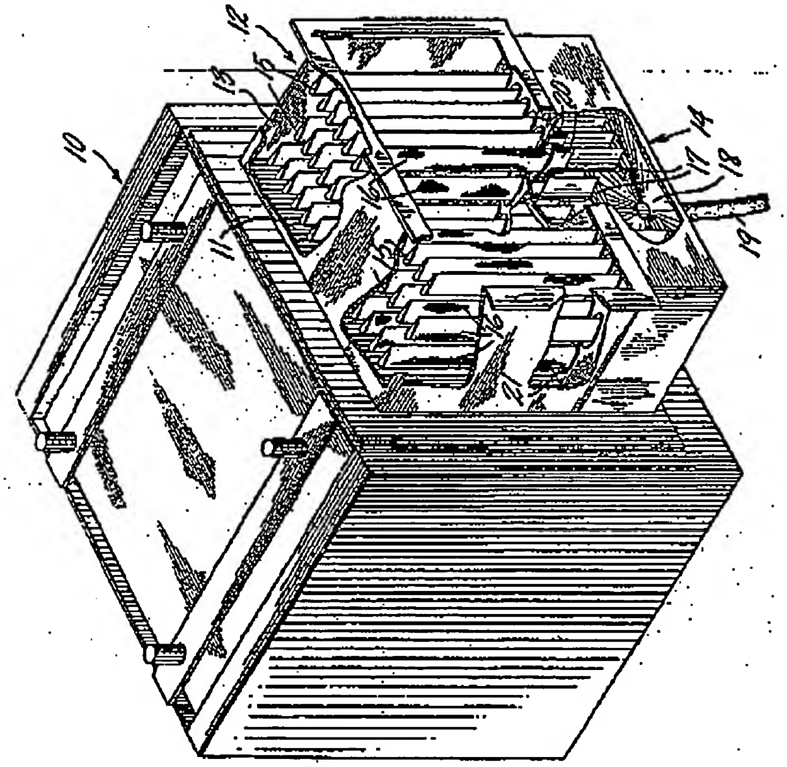

FIG. 1

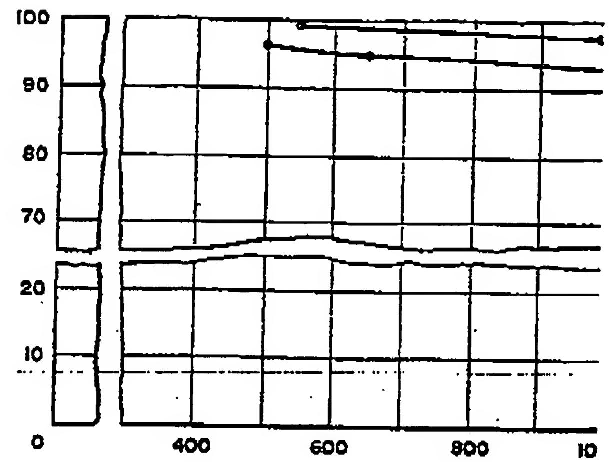

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FIG. 5

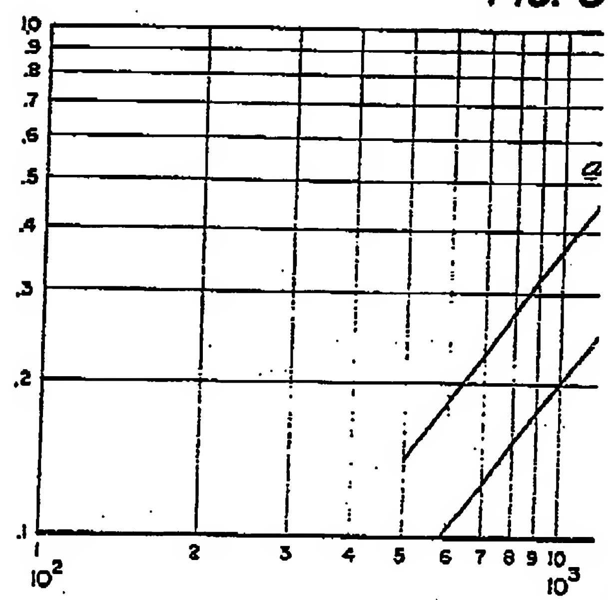

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FIG. 6

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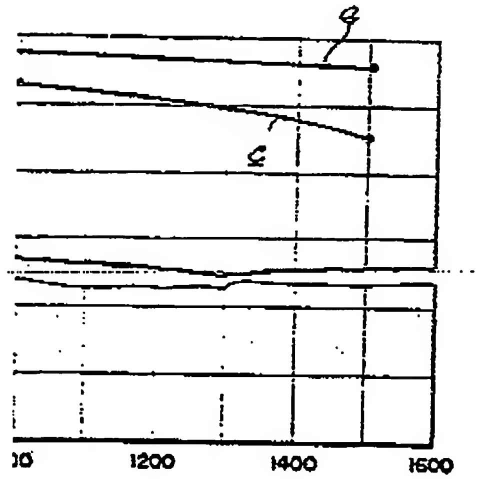

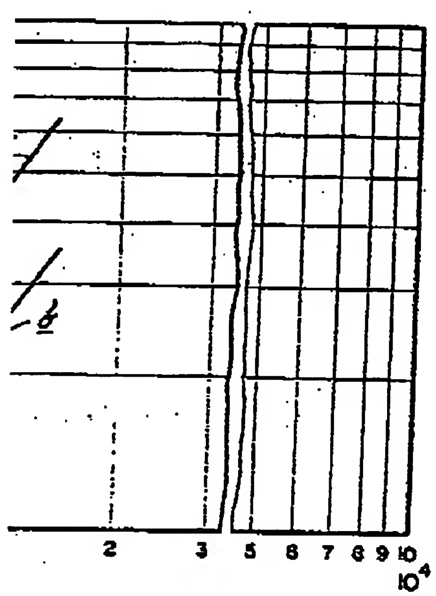

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SHEET 2

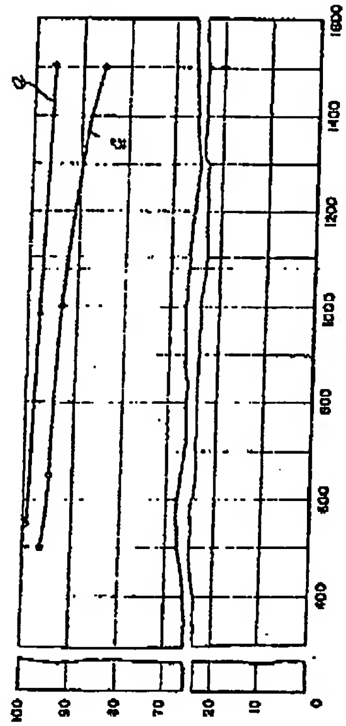

FIG. 5

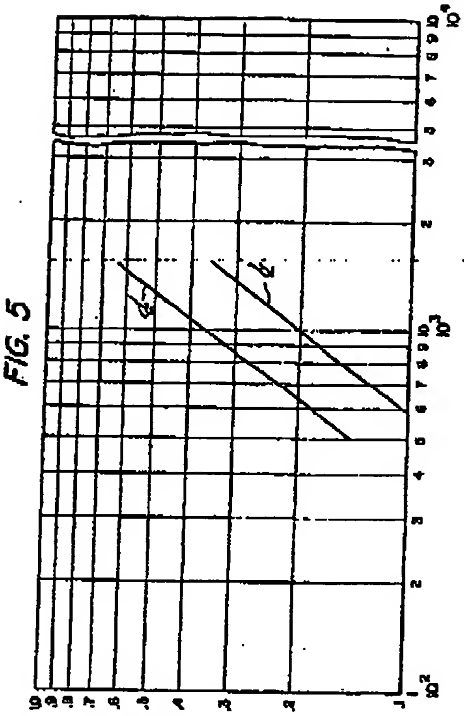

FIG. 6